Appendix D

Groundwater Pump Test

Evaluation of Groundwater Pumping in Rainelle, West Virginia

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Environmental & Water-Resource Consultants

December 23, 2005

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REPORT

Section 1
Introduction

S.S. Papadopulos & Associates, Inc. was retained by Potomac-Hudson Engineering, Inc. (PHE) to develop a groundwater flow model to simulate groundwater conditions in Rainelle, West Virginia. The groundwater model was used to evaluate the availability of groundwater as a water source for the proposed power facility and to evaluate potential impacts to local pumping wells from groundwater withdrawals.

Groundwater flow was simulated using MODFLOW-2000 (Harbaugh et al., 2000), the most widely used program in simulating groundwater flow. For the purposes of this analysis, a GIS application was developed to assist in data management and to generate necessary input files for the model.

Section 2
Groundwater Flow Analysis

Geographic Information System (GIS) Application

The GIS coordinate system was registered to the NAD 1983 West Virginia South Zone State Plane with units in feet. The following vector and raster data were included:

- A digitized basemap of roads and hydrologic features.
- Georeferenced geologic maps of Fayette (White, 1919) and Greenbrier (Price, 1937) Counties.
- A Topographic map of the area.
- A Digital Elevation Model (DEM) with 10-foot resolution.
- Mapped locations of the pumping and observation wells.
- Mapped location of the National Oceanic and Atmospheric Administration (NOAA) East Rainelle station.
- Mapped location of the U.S. Geological Survey (USGS) streamflow station on Meadow River.

Conceptual Model

The groundwater system in the study area was conceptualized as consisting of three major units: a saturated surficial alluvial overburden, 5-15 feet thick; a layer of interbedded red to green shales, sandy shales and sandstone, 25-50 feet thick (intermediate layer); and an underlying fractured sandstone layer, at least 100 feet thick. The production and deep observation wells are open to both the intermediate and sandstone layers.

The geologic units in the vicinity of Rainelle dip to the northwest; the dip is calculated to be approximately 120 feet per mile based on the structure contour map of the base of the Sewell Coal prepared by Price (1937). As a result, the sandstone unit in which the production and observation wells are completed, which is at a nominal depth of 50 feet below ground surface at Rainelle, directly underlies the alluvium in the valleys of Sewell Creek and Little Sewell Creek to the south and east of Rainelle. For the purposes of this analysis, the elevation contours of the base of the Sewell Coal were digitized and used to calculate the average dip of the formations. Given known elevations of the sandstone formation at the observation wells, the dip of the sandstone unit was determined and then three-dimensionally superimposed on the ground surface DEM, delineating the areas of sandstone outcrop.

The intermediate layer acts as an aquitard, allowing limited vertical leakage. There is limited hydraulic connection between the surficial aquifer and the sandstone aquifer. Although there is limited data regarding hydrogeologic conditions in the area, groundwater movement appears to occur primarily through horizontal fractures in the sandstone formation. According to a study by Wyrick and Borchers (1981), groundwater movement in the valleys of the

Appalachian Plateaus Physiographic Province of West Virginia is the result of stress relief fracturing. Stress relief, the removal of compressional stresses on underlying rocks by erosion of overlying rocks, results in predictable fracture patterns in valley; fractures are generally horizontal under valley floors and are generally vertical along valley walls. The horizontal fractures beneath the valley floor typically develop along bedding plane partings. Horizontal fracturing is limited beyond the valley walls, and thus the valley walls essentially act as low permeability barriers. Recharge to the aquifers primarily occurs via the vertical fractures along the valley walls. In the study area, the valleys along Sewell Creek, Little Sewell Creek, and Meadow River, define the areal extent of the aquifer systems as described above.

Aquifer Test Data Analysis

The data from the aquifer tests performed by PHE at PW-1, PW-3, and PW-4 were reviewed and analyzed using the commercially available software AQTESOLV (Duffield, 2002). For purposes of analyzing the aquifer test, the groundwater system was conceptualized as a leaky aquifer system. The analytical solution developed by Hantush (1960) for a leaky confined aquifer with storage in the aquitard was used to analyze the drawdown data from the tests.

Analysis of the data from the deep observation wells for the 72-hour pump test at well PW-1 indicated that the effective transmissivity and storativity in the vicinity of PW-1 are approximately 700 ft^2/d and $4x10^{-6}$ respectively. The effective transmissivity and storativity in the vicinity of PW-3 range between 470 and 1070 ft^2/d, and $1x10^{-5}$ and $1x10^{-7}$, respectively. It should be noted that during the aquifer tests at wells PW-1 and PW-3, at all observation wells, high drawdown was measured very soon after commencement of the test, which is indicative of a highly fractured aquifer.

Analysis of the available drawdown data in the vicinity of well PW-4, indicated that the effective transmissivity and storativity are approximately 400 ft^2/d and $2x10^{-6}$, respectively. The aquifer transmissivity is much lower at PW-4 than at PW-1 and PW-3.

The purpose of the aquifer test analyses was to provide an indicative range of values for transmissivity and storativity, to be used as initial estimates of aquifer parameters in the calibration of the groundwater flow model.

Baseflow Analysis

Baseflow, the groundwater contribution to total streamflow, for the streams in the study area was calculated using automated hydrograph separation techniques. The Meadow River station at McRoss, West Virginia, located approximately two miles northeast of well PW-1, was the closest station to the study area. Discharge data were downloaded from the USGS National Water Information System. The available data spanned the period from 1979 to 1982. The drainage area of that station was 163 square miles. Baseflow discharge was calculated using BFI (Wahl, 2001), a software package for automated hydrograph separation. The average calculated baseflow for the period that data were available was 9.5 inches per year.

A rough estimate of the appropriate areal extent of the model was determined based on the baseflow calculation. Assuming all necessary groundwater withdrawals for the power plant could be derived from baseflow, the minimum areal aquifer extent to guarantee such withdrawals would be equal to the pumping rate of 760 gallons per minute divided by the baseflow rate of 9.5 inches per year, or approximately 2.3 square miles. Given the hydrogeologic and topographic conditions in the study area, and to account for boundary effects, a model area of approximately 50 square miles was considered for the model.

Model Description

The groundwater model encompasses an area of approximately 50 square miles, defined by a grid of 352 rows and 152 columns of variable spacing. The vertical model discretization includes three layers, for the representation of the alluvial overburden, the intervening aquitard layer, and the sandstone layer. The model orientation is 35 degrees east of north; which means that the model columns are oriented northeast – southwest (Figure 1).

Grid spacing along model rows varies between 60.625 feet and 485 feet. Grid spacing along columns varies between 88.75 feet and 355 feet. The top layer has variable thickness to distinguish between the alluvium, where the thickness is equal to 15 feet, and the sandstone formation everywhere else, where the thickness is equal to 10 feet. The middle layer, which represents the interbedded layers of sandstone and shales, has a thickness of 50 feet, except underneath the alluvium, where the thickness is equal to 35 feet. Finally, the bottom layer, representing the sandstone formation, has a uniform thickness of 100 feet. The middle layer was assumed to be not present in areas where the sandstone layer directly underlies the alluvium; this was simulated by specifying a very large vertical hydraulic conductivity for the middle layer in these areas.

The model boundary conditions included no-flow boundaries along the model perimeter, and river nodes in the top layer along the major streams. All river nodes were assigned a constant hydraulic head.

Different hydraulic conductivity values were specified in the upland and valley areas in all layers. However, the sandstone unit underlying the alluvium along Meadow River in the vicinity of well PW-4 was assigned upland conductivities, to reflect the conclusions from the aquifer test at that well. This suggests that stress relief fracturing is not prevalent in areas where the valleys are very narrow.

Hydraulic properties of the model, including horizontal and vertical hydraulic conductivity and storage coefficient, were determined through the calibration process. Specific yield for the top layer was set equal to 0.1.

The pumping wells PW-1, PW-3, PW-4, CW-1, and CW-2 were represented by cells in the bottom layer with assigned pumping rates based on known and/or assumed pumping schedules.

Model Calibration

Model calibration was facilitated through the use of PEST (Doherty, 2005), a nonlinear parameter estimation and model calibration software. Model calibration parameters included:

- Horizontal and vertical hydraulic conductivity.
- Specific storage.

The flow model calibration targets included measured drawdown at the deep observation wells during the aquifer tests at wells PW-1 and PW-3. For simplicity, the models were calibrated to the aquifer tests results independently. Model calibration to the aquifer test data from well PW-4 was performed to estimate hydraulic parameters of the sandstone formation in the vicinity of PW-4.

Horizontal and vertical hydraulic conductivities and storage coefficients were determined through the iterative calibration procedure. The calibrated hydraulic properties of the sandstone aquifer for the two models are summarized in the following table for models calibrated to aquifer tests at PW-1 and PW-3:

Calibration Results

	Valley		Uplands	
	PW-1	**PW-3**	**PW-1**	**PW-3**
Horizontal Conductivity (ft/d)	100.6	100.6	4.7	4.7
Vertical Conductivity (ft/d)	8.6×10^{-5}	6.1×10^{-6}	2.0×10^{-3}	4.1×10^{-3}
Specific Storage (per foot)	1.2×10^{-6}	2.3×10^{-6}	1.0×10^{-8}	1.0×10^{-8}

The values of aquifer parameters calculated from the calibration process were similar for both the calibration to the aquifer test data from PW-1 and the calibration to the aquifer test data from PW-3, with the exception of vertical hydraulic conductivities in the valley, which differed by almost an order of magnitude. Plots of calculated drawdowns and observed drawdowns from the aquifer test of PW-1 are shown in Figure 2, for calibration to the aquifer test results at well PW-1. A plot of the calculated and the observed drawdowns from the aquifer test of PW-3 are shown on Figure 3.

After calibration to aquifer test data from PW-4, the calculated horizontal hydraulic conductivity of the sandstone formation underlying the alluvium along Meadow River in the vicinity of PW-4 was 3.0 ft/d.

Model Predictions

The calibrated model was run for 25 years, with a specified production rate for PW-1 of 760 gpm, to simulate long-term drawdown in the groundwater system. The model was run using parameters obtained from calibration to aquifer test results at PW-1 and PW-3 separately, to compare aquifer response for high and low vertical conductivity conditions in the valley. In addition, combined pumping from wells PW-1 and PW-3, each at a rate of 380 gallons per minute, was simulated under both high and low valley conductivity conditions.

The results of the model runs using the parameters obtained from calibration to aquifer test results at well PW-1 are shown in Figure 4. The results of the model runs using the aquifer parameters obtained from calibration to aquifer test results at well PW-3 are shown in Figure 5. Simulated pumping from PW-1 and PW-3 at equal rates for high and low vertical conductivities resulted in drawdowns shown in Figures 6 and 7, respectively.

The calculated drawdowns after 25 years of pumping at wells CW-1 and CW-2, with hydraulic parameters from calibration to well PW-1 aquifer test, are approximately 43 and 40 feet respectively. The calculated drawdown at production well PW-1 is approximately 56 feet. For hydraulic parameters from calibration to well PW-3 aquifer test, the simulated drawdowns at CW-1 and CW-2 are approximately 35 and 32 feet respectively. The calculated drawdown at production well PW-1 is approximately 47 feet. The drawdown at PW-1 was assumed to be equal to the average drawdown in the model grid cell in which the well is located. The foundation for this assumption is the drawdown data from the aquifer tests which indicated that drawdown is relatively constant for a large radial distance around the production well, likely as the result of very high transmissivity in some fractures.

When the model was run for combined pumping from wells PW-1 and PW-3 with hydraulic parameters from calibration to PW-1 aquifer test, the simulated drawdowns at wells CW-1 and CW-2 are approximately 42 and 41 feet, respectively. The calculated drawdowns at pumping wells PW-1 and PW-3 are 45 and 44 feet, respectively. For hydraulic parameters from calibration to well PW-3 aquifer test, the simulated drawdowns at both CW-1 and CW-2 are approximately 33 feet. The calculated drawdowns at both pumping wells PW-1 and PW-3 are 36 feet.

In order to address concerns regarding short-term drought periods, available data from observation wells in Greenbrier, Fayette, and Nicholas Counties, which encompass the drainage basin of Rainelle, were downloaded from the USGS NWISWeb Database. Water level data were considered only for wells with available data spanning more than one year and with sufficient number of measurements each, regardless of the formation in which they were completed. The maximum water level fluctuation for all wells did not exceed 12 feet, which could be considered as additional drawdown to reflect short-term drought conditions.

Section 3
Summary and Conclusions

Four simulations of long-term pumping at a rate of 760 gpm were conducted with the groundwater model that was developed:

- Model using aquifer parameters estimated from PW-1 aquifer test data – PW-1 pumping at a constant rate of 760 gpm;
- Model using aquifer parameters estimated from PW-3 aquifer test data – PW-1 pumping at a constant rate of 760 gpm;
- Model using aquifer parameters estimated from PW-1 aquifer test data – PW-1 pumping at a constant rate of 380 gpm and PW-3 pumping at a constant rate of 380 gpm;
- Model using aquifer parameters estimated from PW-3 aquifer test data – PW-1 pumping at a constant rate of 380 gpm and PW-3 pumping at a constant rate of 380 gpm.

The results of these simulations indicate that long-term pumping at a rate of 760 gpm will produce significant drawdowns within the sandstone aquifer. Our analysis, though, shows that it is feasible to produce 760 gpm during a 25 year period. These analyses, though, are based on the results of relatively short term aquifer tests and a conceptual geologic model that is based on limited field data. It is possible that actual drawdown will be larger than simulated in this study if actual field conditions differ from the simulated conditions.

A major uncertainty in our understanding of the groundwater system is the characteristics of the sandstone aquifer unit beneath the upland areas. The drawdown pattern reflects the effects of low hydraulic conductivity beneath the upland areas and enhanced leakage from the water table along the valley walls. Vertical hydraulic conductivities in the upland areas appear to be more critical than those in the valley with respect to expected drawdowns. Due to the limited available data, it is not possible to draw positive conclusions as to whether the model with higher vertical conductivities or the model with lower hydraulic conductivities better describes the hydrogeologic conditions in the study area. Both models predict relatively similar drawdowns at the municipal wells. If the sandstone unit is relatively impermeable beneath the upland areas, as the result of limited horizontal fracturing, then the model may be an accurate representation of the groundwater system, though in the model we assumed significant permeability in the upland areas. If the sandstone unit beneath the upland areas is much less permeable than assumed in our analyses, then the actual drawdowns from long-term pumping will be greater than those shown on the figures.

Some of the uncertainty inherent in our evaluations could be reduced by conducting longer aquifer tests at PW-1 and/or PW-3 and by monitoring water levels during the tests in wells located in the upland areas and wells located in the valleys much further from the pumping wells than was done in previous testing. Our recommendation is that a test be conducted for at least 30 days, the minimum time required to significantly improve our current understanding of the system. It must be recognized that the results of additional testing may well indicate that long-term pumping at a rate of 760 gpm is not sustainable from the sandstone aquifer.

Section 4
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FIGURES

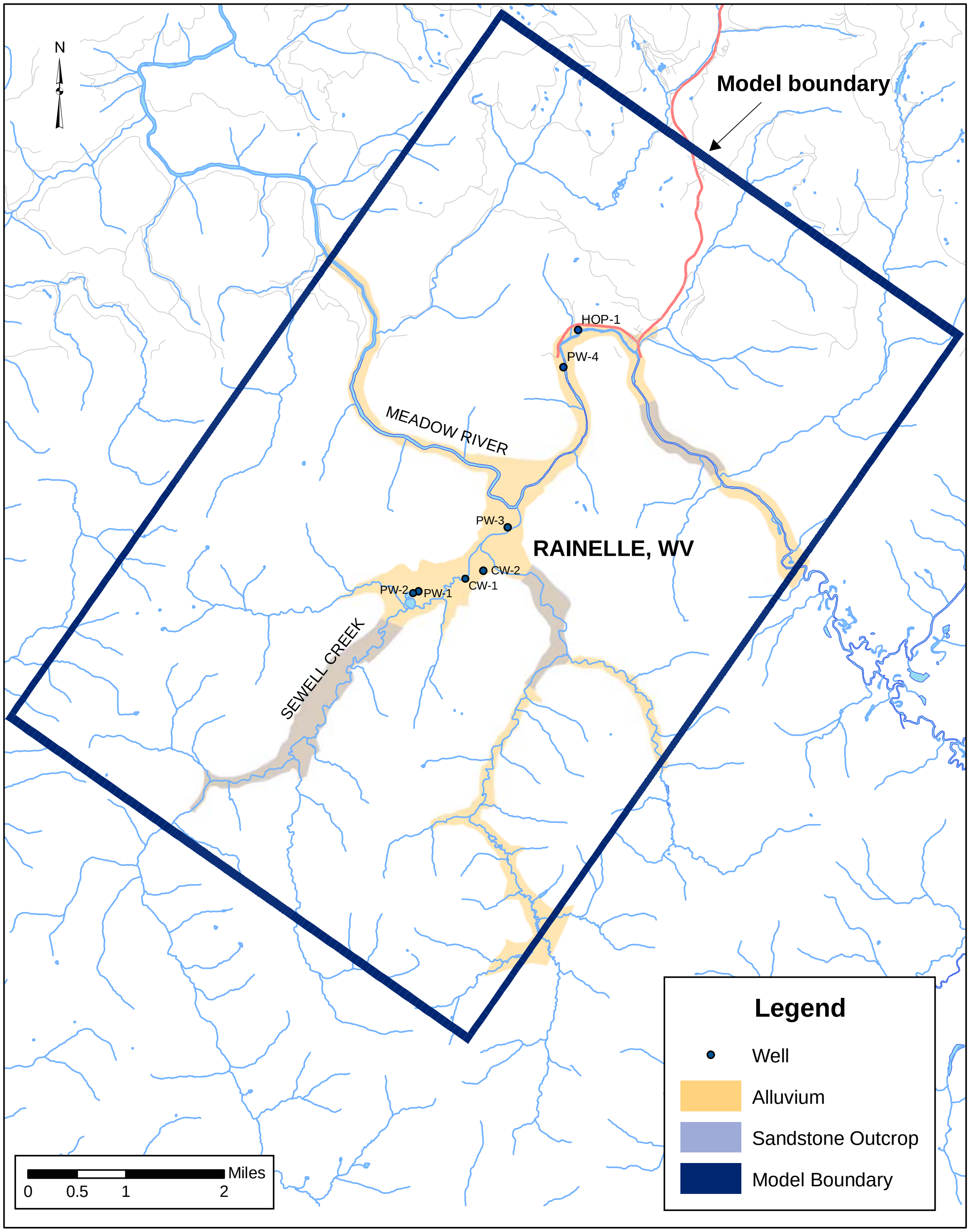

Figure 1 Location Map

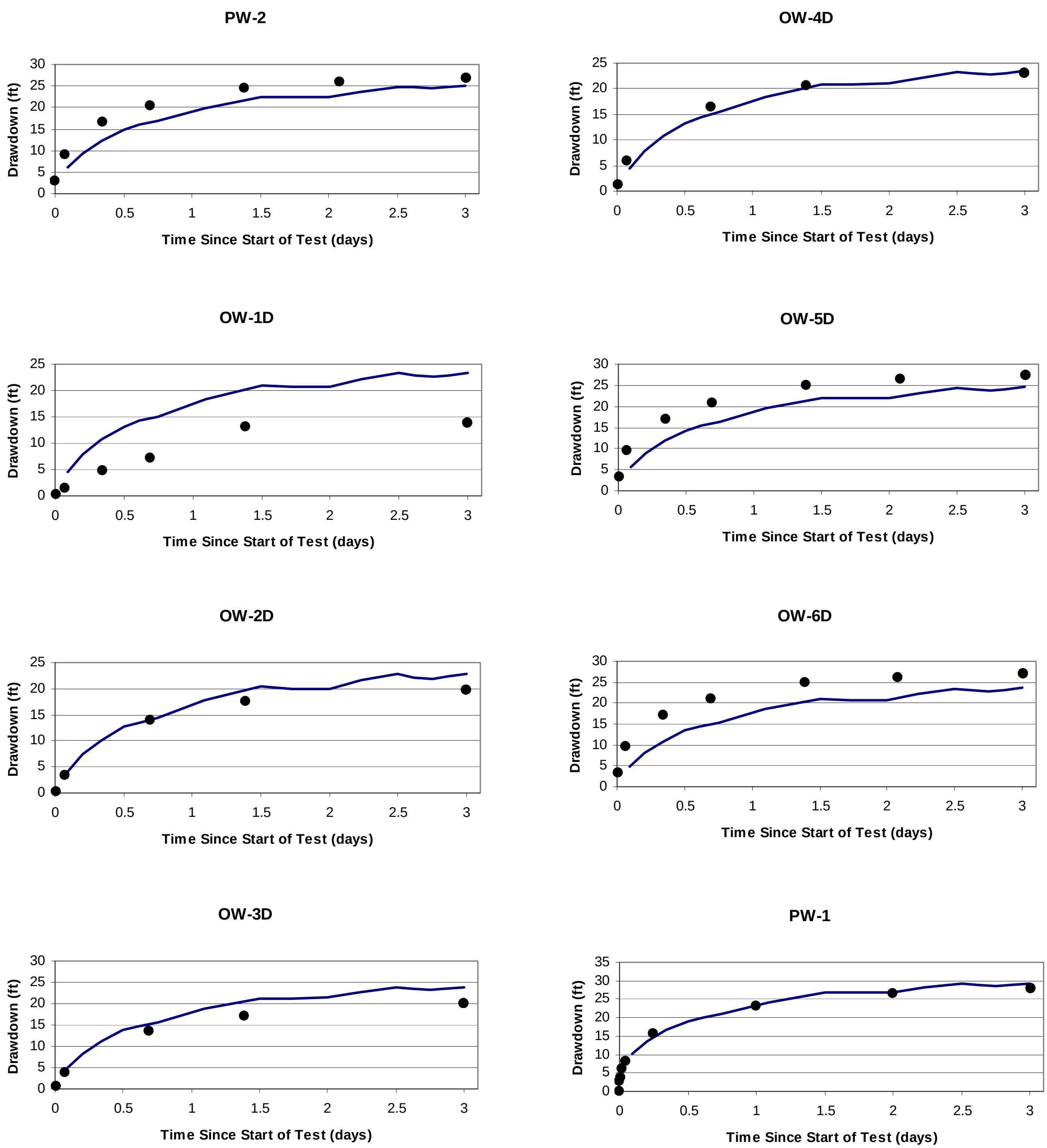

Figure 2 Observed versus Simulated Drawdown,
Model Calibrated to Aquifer Test Results at Well PW-1

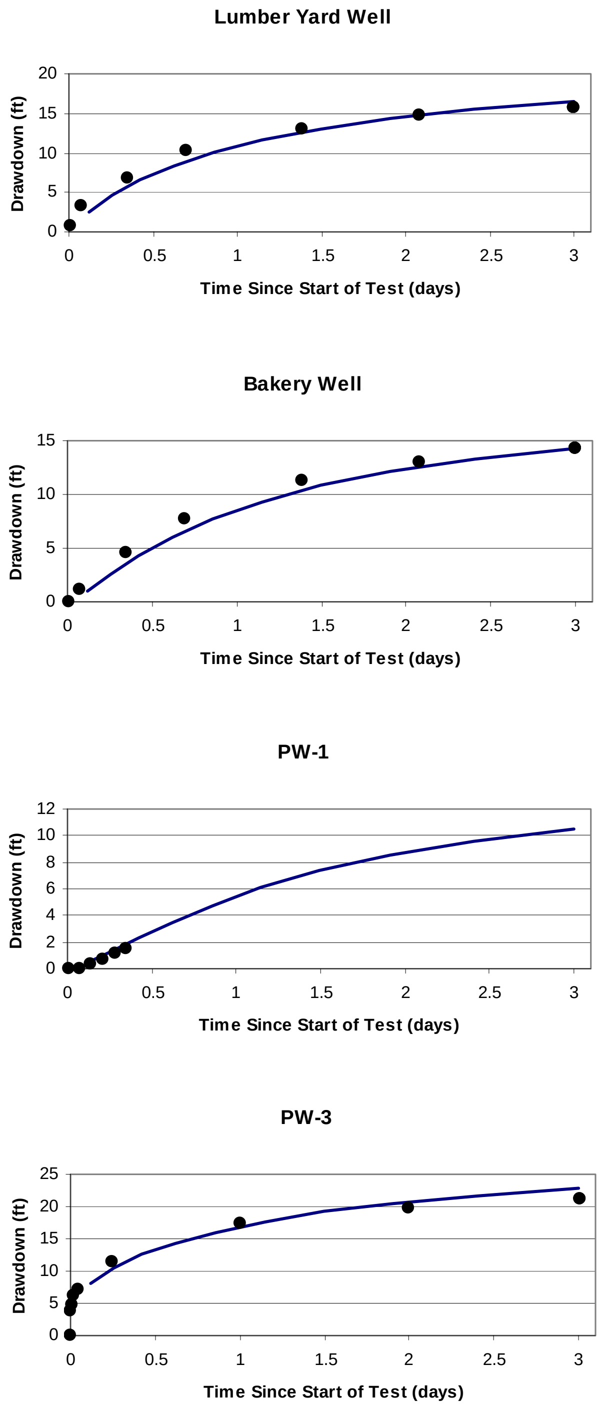

Figure 3 Observed versus Simulated Drawdown,
Model Calibrated to Aquifer Test Results at Well PW-3

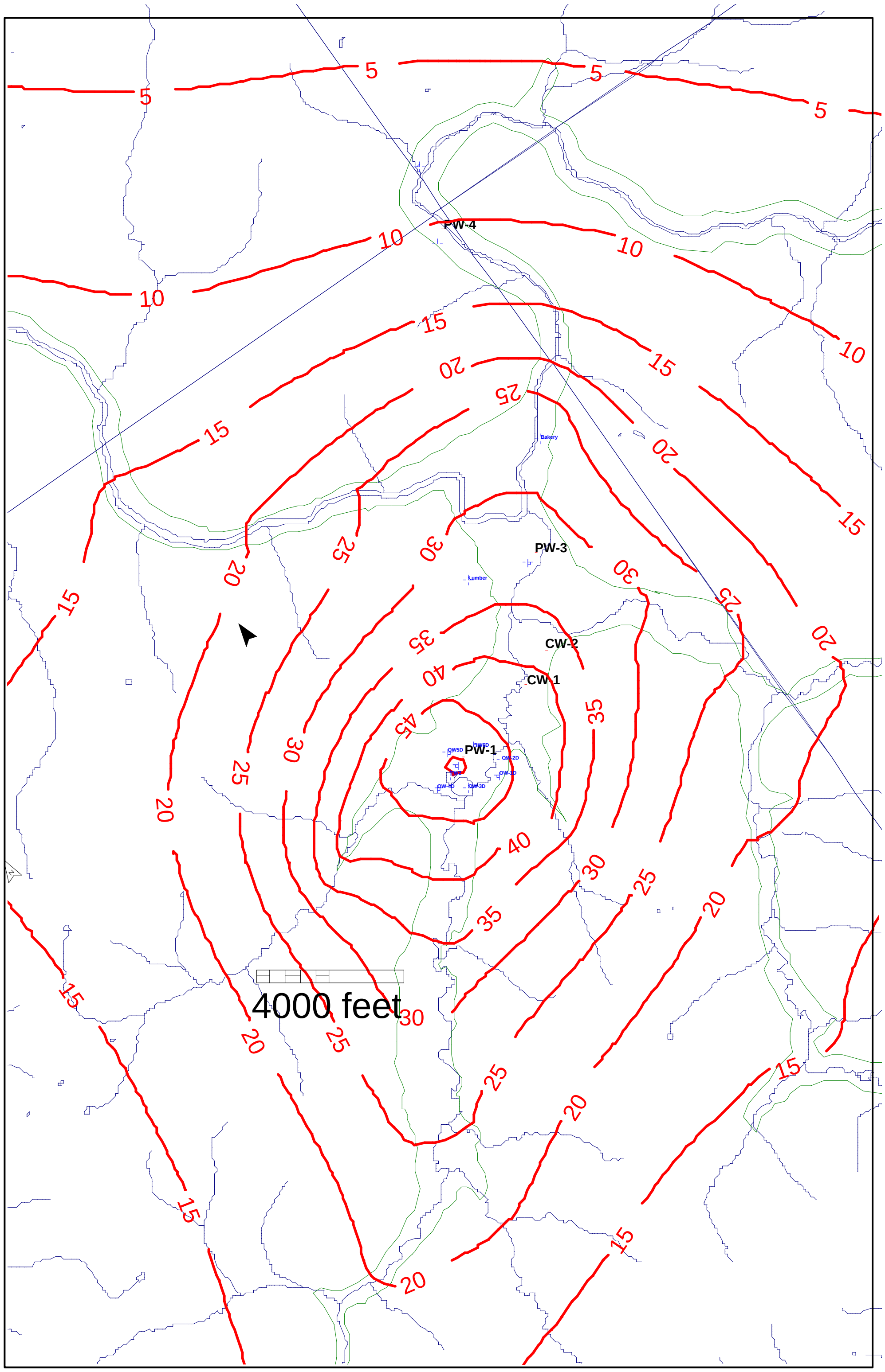

Figure 4 Simulated Drawdown after 25 Years,
Model Calibrated to Aquifer Test Results at Well PW-1

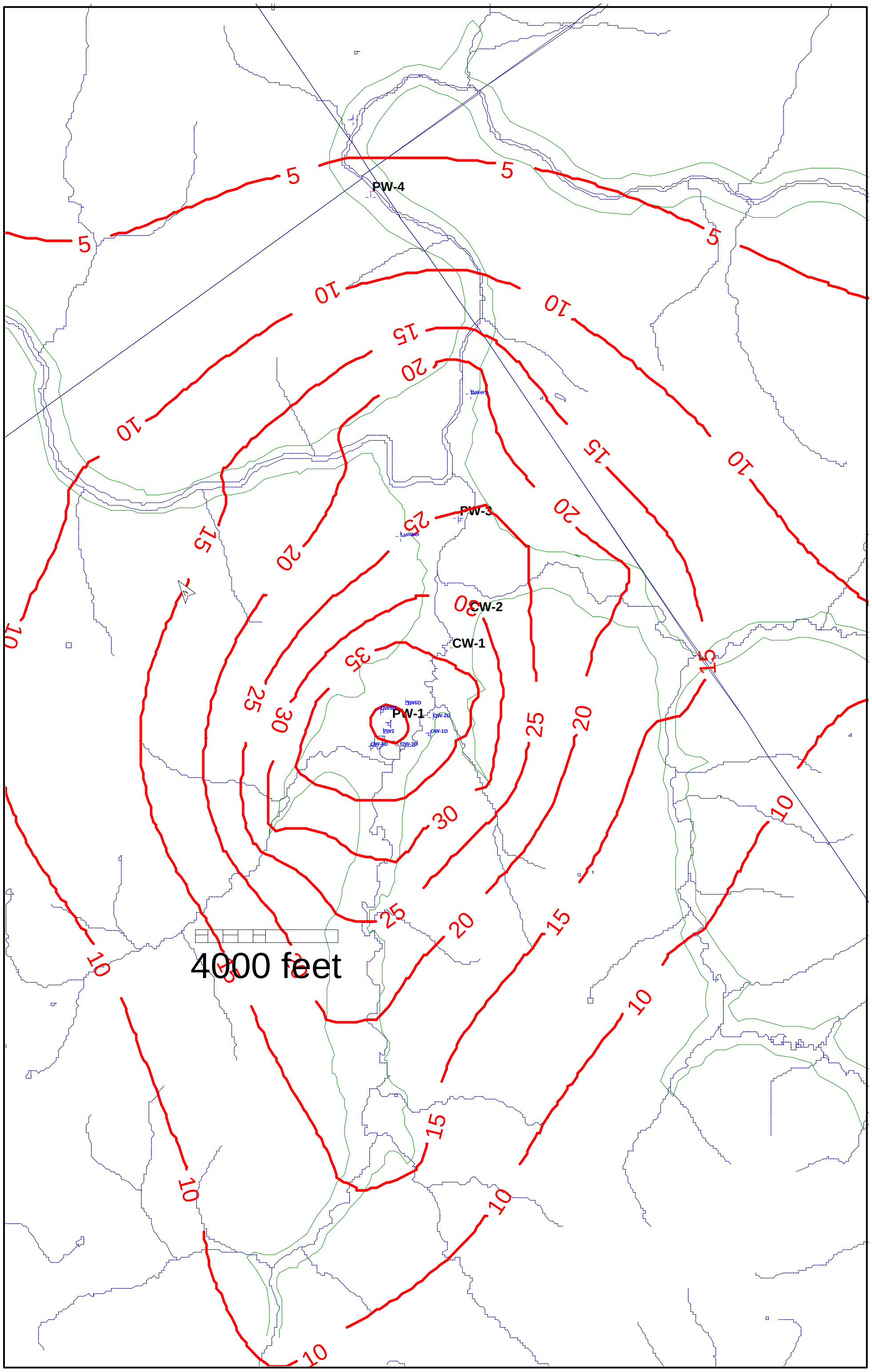

Figure 5 Simulated Drawdown after 25 Years,
Model Calibrated to Aquifer Test Results at Well PW-3

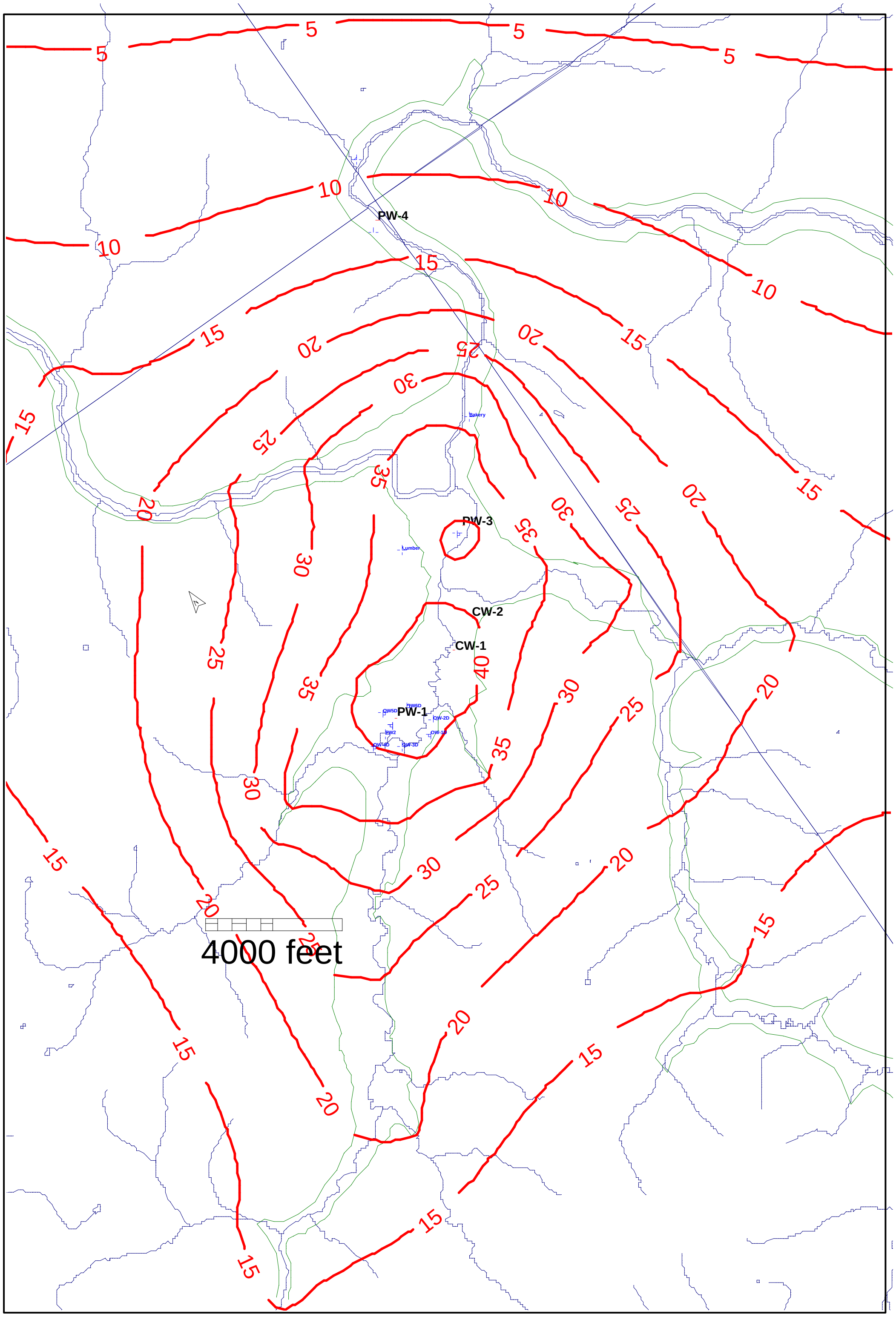

Figure 6 Simulated Drawdown after 25 Years, Pumping from PW-1 and PW-3, Model Calibrated to Aquifer Test Results at Well PW-1

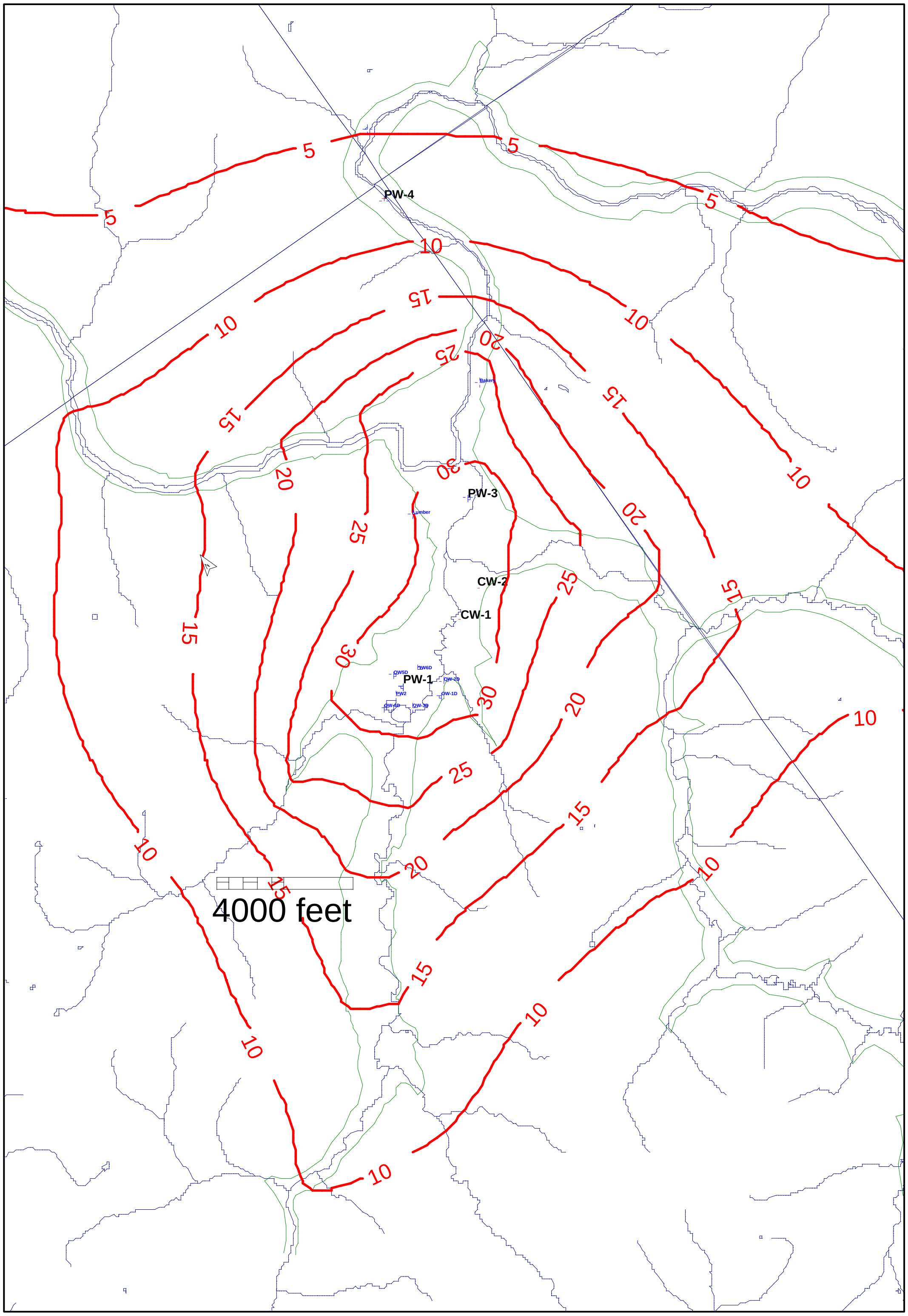

Figure 7 Simulated Drawdown after 25 Years, Pumping from PW-1 and PW-3, Model Calibrated to Aquifer Test Results at Well PW-3